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A Hybrid Grey Decision Methodology in Social Sustainable Supplier Selection

Hadi Nasseri [1], Han-Kwang Chen [2], Kuang-Zong Huo [3] and Yen-Fen Lo [4,*]

1 Department of Mathematics, University of Mazandaran, Babolsar 4741613534, Iran
2 Department of Applied Foreign Languages, JinWen University of Science & Technology, New Taipei City 231, Taiwan
3 Department of Business Administration, China University of Technology, Taipei 116, Taiwan
4 Department of Business Administration, Shih Chien University, Taipei 104, Taiwan
* Correspondence: fenlo@g2.usc.edu.tw

Abstract: In the past decade, sustainable supply chain management has received much attention from practitioners and academics due to the heightened emphasis on environmental, economic, and social sustainability by customers, for-profit and non-profit institutions, community organizations, legislation, and government oversight. Evaluating and selecting a suitable supplier is considered a critical choice, crucial in supply chain management. Social sustainability in the supplier selection process is an important factor that has not received sufficient attention from academicians. Social and societal challenges are increasingly impacting supply chains. To tackle this challenge in the agricultural section of nations with emerging economies, this study proposed a new methodology using Grey FUCOM (Full Consistency Method) and Gray PROMTHEE (Preference Ranking Organization Method for Enrichment Evaluation) methods for evaluating the social sustainability of wheat and barley seed production companies. This study assists seed users in identifying the most significant supplier selection criteria and one of the most effective suppliers for ecological sustainability throughout the supply chain while maintaining market competitiveness. The results demonstrated a consistent and dependable rating behavior about the weight coefficients of the criteria. Improving the procedures used to evaluate wheat and barley seed suppliers results in a healthier society. So, the proposed model can efficiently evaluate a critical component of the food supply chain in the early stages.

Keywords: social sustainability; supplier evaluation; grey numbers; FUCOM; PROMTHEE II; agricultural supply chain

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1. Introduction

As a result of the rapid development of network technology and the globalization of the economy, buying management has emerged as a crucial success factor in Supply Chain Management (SCM). The assessment and selection of suppliers compatible with agile systems are among the most significant issues that purchasing managers face. Multi-Criteria Decision-Making (MCDM) techniques have been used in supplier selection research. This combination of the increasing significance of enterprises includes economic and environmental factors in source control in production processes and protecting the environment. Sustainability refers to providing today's demands without jeopardizing the requirements of the coming generations. As one plans and implements the conveyance of information, a greater variety of consumers and stakeholders get access to more data about the operations of supply chains. Consequently, concerns like lousy working conditions at the suppliers' facilities are frequently highlighted. People, politicians, and Non-Governmental Organizations (NGOs) are asking that firms be held more responsible for their actions involving their supply chains.

Consequently, social practices and behaviors in business and the supply chain cover all methodologies that influence how a company aids humanity's growth or keeps us safe from damage, which includes both favorable and unfavorable elements. A purchasing organization must carefully evaluate and choose its suppliers to combat negative societal perceptions more comprehensively. The Resource-Based View (RBV) [1] is a helpful conceptual basis for determining whether Social Sustainability (SS) is required for business production operations. RBV represents businesses that may establish competitive skills and advantages by choosing socially responsible suppliers.

SS providers provide critical value assets that enhance corporate success, encourage operational capabilities, and decrease expenses. Supplier selection is an essential and tactical choice in production processes that may enhance the inclusive development of merchandise and services. It is crucial for the reputation of a purchasing agency to choose and collaborate with environmentally accountable providers. The sustainable process for selecting suppliers may assist in assessing and evaluating purchasing performance based on economics while also considering ecological and social capacities and characteristics. Consequently, through RBV, choosing responsible manufacturers may aid in developing or maintaining an organization's ethical and other environmental skills, contributing to its planned product differentiation. The supply chain operates under an MCDM circumstance. Numerous decision-making strategies and combinations have been employed to assess and choose suppliers. The literature thoroughly explains multiple approaches for selecting suppliers. Haeri and Rezaei [2] proposed a comprehensive, grey-based supplier selection technique that combines commercial and environmental variables. By utilizing the best–worst method with fuzzy grey neural networks to depict the links among the criteria, they presented an innovative way for the weighing assessment. Yazdani et al. [3] proposed a two-stage sustainable supplier assessment methodology for food supply chains based on a combined judgment by experts with complex perspectives that take environmentally conscious businesses and subcontractors into account. Nafei et al. [4] developed a multi-attribute group decision-making method to address hotel location selection problems by providing an optimized score function for rating neutrosophic triplets. Pamucar et al. [5] developed a novel decision-making technique for dealing with the COVID-19 epidemic by evaluating desirability using a causal analysis method (MACBETH) and an individualized complementary distance-based assessment instrument. Asadabadi et al. [6] developed a distinctive factor selection structure to assist in evaluating company suppliers in light of prospective eventualities. The framework contains the scaled MCDM method, the best–worst technique, and the strategy for scoring possibilities based on an approximate representation of the ideal response. By creating an innovative hamming distance within single-valued neutrosophic sets, Nafei et al. [7] suggested an extended TOPSIS method for group decision making under uncertainty in which the experts indicate metadata about the criteria using neutrosophic values. Alikhani et al. [8] proposed a MADM technique that utilized numerical observational research and computational modeling. They employed interval type-2 fuzzy sets to characterize the data inputs of decision makers. They provided a variant of the DEA framework that incorporates unacceptable and undesired inputs and outcomes for evaluating the vendors. Stevic et al. [9] suggested an order of alternatives based on a satisfactory methodology for a sustainable SS in a polyclinic. The benefits of the recommended approach involve taking into account multiple demands and competitors without losing the privacy of the approach, a comparison of an anti-ideal and an ideal solution at the outset when developing a starting framework and a more precise evaluation of the efficacy of both answers. Afrasiabi et al. [10] presented an exhaustive structure to analyze suppliers based on ecologically conscious and robust settings, integrating established and robust fuzzy MCDM methodologies. Nafei et al. [11] proposed a neutrosophic autocratic co-operative MCDM strategy for dealing with building supplier selection problems. The neutrosophic values demonstrate the comparative importance of possibilities over their features. The suggested approach updates the decision-maker weights if the team agreement level matches or exceeds the specified threshold number.

In this study, a hybrid methodology, using FUCOM (Full Consistency Method) and PROMTHEE (Preference Ranking Organization Method for Enrichment Evaluation) based on Grey Theory has been proposed to evaluate the performance of wheat and barley seed production companies from a social sustainability point of view. The motivation for this study stems from the fact that several times a year, the seed users, especially the farmers, need to receive clear information about the suppliers' performance from various perspectives. Furthermore, due to the increasing importance of social sustainability in emerging economies, we intend to overlook this periodic challenge and provide understandable and unambiguous information regarding the ranking of wheat and barley seed production companies from a social aspect. This research contributes by introducing an innovative approach that employs the Grey FUCOM and Grey PROMTHEE methods for evaluating the social sustainability of a particular company in the agricultural sector of emerging economy regions. By tackling the absence of consideration toward social sustainability in supplier selection, this study seeks to support seed users in identifying essential requirements that efficient manufacturers use for sustainable development, thereby promoting better public health and enhancing the processes for assessment at the beginning of the supply chain for food.

The rest of this paper is organized as follows: Section 2 provides an overview of sustainable and socially sustainable supplier selection. Section 3 presents the proposed methodology's background on FUCOM, PROMTHEE methods, and grey theory. The research methodology and its preliminaries are discussed in Section 4. Section 5 executes a comprehensive evaluation of agriculture. The sensitivity analysis results are presented in Section 6. And finally, the conclusion is provided in Section 7.

2. Sustainable Supplier Selection

Supply chain operations with sustainability considerations have become an increasingly important issue in recent years. While diverse interpretations of sustainability exist, one central concept that helps to operationalize sustainability is the triple bottom line approach, where a minimum performance is to be achieved in the environmental, economic, and social dimensions. The responsibility for sustainability cannot be given to a separate entity; it must be a part of everyone's job in an SSC, from the suppliers to the top management.

2.1. Supply Chain Methodologies

Supply chain strength generally depends on the linkage between the number and quality of the suppliers and customers in a country and the three dimensions of sustainable development, namely, environmental, economic, and social.

Many scholars have proposed various methodologies regarding the inevitable importance of sustainable supplier selection. In this paper, the literature has been restricted to sustainable supplier selection methodologies since 2012, including those using the fuzzy interference system [12], Fuzzy AHP (Analytic Hierarchy Process), Fuzzy Multi-Objective Linear Programming [13], Decision-making Trial and Evaluation Laboratory (DEMATEL) approach [14], Fuzzy TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) [15], Rough set theory and Data Envelopment Analysis (DEA) [16], (Analytic Network Process) ANP and improved GRA (Grey Relational Analysis) [17], Fuzzy axiomatic design [18], a fusion of fuzzy information approach, 2-tuple linguistic [19], Bayesian framework with Monte Carlo Markov Chain (MCMC) simulation [20], Grey DEMATEL [21], AHP and Taguchi loss functions [22], ANP and improved Grey relational analysis [23], the integrated framework of enhanced Russell measure and data envelopment analysis [24], the integrated Fuzzy sets, and (Viekriterijumsko Kompromisno Rangiranje) VIKOR and TOPSIS [25].

In earlier research, Sethi [26] introduced a taxonomy describing corporates' social obligations and responsibilities, including voluntary social duties. Social sustainability is paramount in the manufacturing supply chain because of the need for increased stakeholder awareness regarding not only 'where' the products are made but also 'how' and 'in what conditions they are produced. Sharma and Ruud [27] defined social sustainability as an "ethical code of conduct for human survival and outgrowth that needs to be accomplished in a mutually inclusive and prudent way." Addressing social issues in supplier locations can help achieve upstream social sustainability. However, social problems and antecedents of social sustainability vary across geographic areas. Also, the number of research works in the literature on socially sustainable supplier selection from emerging economies is limited. This study introduces a new methodology for evaluating social sustainability through supplier selection in the agriculture sector of an emerging economy nation, which previous researchers have not studied.

2.2. Social Sustainable Supplier Selection

There are few decision-support frameworks for social sustainability in the supplier selection literature. Mani et al. [28] have comprehensively analyzed socially sustainable supplier selection. Their study unifies the literature on supplier, manufacturer, and consumer responsibility. It introduces the idea of Supply Chain Social Sustainability (SCSS), which addresses social concerns along the whole (upstream and downstream) supply chain. They also investigated the advantages gained by suppliers and purchasers in developing economies from the successful management of such social challenges. Then, they examined the relationship between socially sustainable supplier selection and the competencies of the firm's suppliers, its market reputation, and the learning inside the supply management organization. After that, they provided a strategy for choosing the best supplier based on corporate social responsibilities. Based on grey number theory, Bai et al. [29] proposed an integrated framework, including the Best–Worst Method (BWM) and Interactive and Multi-Criteria Decision-Making approaches. They demonstrated that their suggested framework required fewer pairwise comparisons than competing approaches. Cole and Atiken [30] suggested that the buying organizations are shifting towards a socially responsible purchasing approach, which involves evaluating the suppliers' sustainability commitment before engaging in financial transactions. This change aims to establish socially sustainable supply chains by emphasizing supplier development activities at the pre-selection stage. Liu et al. [31] introduced an extended framework using the evaluation based on distance from the average solution with Pythagorean fuzzy sets. They implemented it to solve the sustainable circular supplier selection in the manufacturing sector. Coşkun et al. [32] developed the Integrated Sustainable Supplier Evaluation & Development Framework (ISSEDF) to support chemical manufacturers in managing supplier relationships according to the economic, environmental, and social facets of sustainability. Liaqait et al. [33] presented a holistic multi-phase decision-support framework to solve the sustainable supplier selection and order allocation problem for the multi-echelon supply chain. Ghosh et al. [34] proposed a green supply chain management framework for evaluating supplier organizations using a real-world supplier selection problem involving three India-based organizations from different industrial segments.

This research employs a decision framework for social sustainability criteria specified by [28]. The present framework has six features, including "work health and safety", "training education and community impact", "contractual stakeholder influence", "occupational health and safety management system", "the rights and interests of workers", and "information disclosure". This research analyzes, ranks, and chooses sustainable suppliers based on the company's social sustainability characteristics.

3. Multi-Criteria Decision Analysis (MCDM)

The acronyms for MCDMs are widely used. Using various criteria, MCDMs aim to organize and resolve decision- and planning-related problems. The goal is to support decision makers who are faced with these problems. For such problems, there is often no one best answer. Consequently, it is vital to employ the selection to sort among the available possibilities. The term "solving" has multiple meanings within the MCDM framework. It may be comparable to picking the "best" choice from a range of readily available possibilities (where "best" can be interpreted as "the most preferred alternative" of a decision maker). Choosing a small number of workable alternatives or grouping options according to various preference categories might also be regarded as "options." Finding solutions can be considered in a variety of ways. It could be likened to selecting the "optimal" option from a variety of easily accessible options (where "optimal" refers to "the most favored option" for a judgment call). Strategies may also entail selecting a limited range of feasible choices or organizing choices into different desired groups. Specific categories of MCDM problems require solutions. Whether the solutions are expressly provided or left to the casual reader is a fundamental difference among MCDM problems.

A few possibilities are acknowledged at the beginning of the solution method for situations involving several criteria. The effectiveness of each option is used to represent it over a range of factors. Identifying the best choice for a judgment or discovering a group of viable options are two approaches to defining the challenge. One may also be interested in the "ordering" and "characterizing" possibilities. Delegate nations' credit ratings are an example of arranging alternatives into a collection of desirability classes, while dividing options into semi is an example of segmentation.

For circumstances containing multiple criteria, just a few options are openly recognized at the start of the solution technique. Each choice is represented by how successful it is given various circumstances. The challenge is in determining the best choice for a selection or creating a list of workable possibilities. Assigning nations' credit scores is an example of sorting choices into a collection of priority taxonomies, while categorizing options into a set of quasi-subcategories is an example of classifying. In this respect, using six exemplary European case studies with varying degrees of complexity, Ramos et al. [35] described and identified goals to promote future development/conservation for every individual in the region's coastline using a transparent approach based on the evaluation of multiple factors. Pervez et al. [36] identified success criteria for enterprises' BOP (Base of the Pyramid) innovations. It explores academic definitions, contrasts opinions on BOP markets, and uses case studies to highlight criteria, such as engaging BOP groups and going beyond selling to low-income people.

DM preference data is required to differentiate between solutions, regardless of the assessment challenge or an architectural issue. For MCDM applications, the duration of the desired information recorded from the DM is frequently employed to categorize the solution approaches. DM preference data is required to differentiate between solutions, whether the issue is a technological problem or an assessment challenge. To categorize the approaches used to solve MCDM questions, the period of preference information recorded from the DM is frequently employed.

During the implementation of the solution, the DM must express preferences for specific methodologies. These interactive strategies or techniques call for "progressive expression of preferences". These techniques have been successfully developed for design issues and multi-criteria assessments.

To explain the suggested supplier assessment and selection approach based on social sustainability, we will first outline the context of the methodology under consideration. Grey numbers are used with the interactive FUCOM and PROMTHEE methodologies in this investigation (system).

3.1. Grey Number (System)

Grey system theory describes processes with unclear knowledge that have broad applicability in treating ambiguity in vague human decision-making processes.

Uncertain systems have, as one of their core properties, partial data. Cases that involve inadequate network information include the following four possibilities:

1. Incomplete information on the components (parameters).
2. The data on the program's design needs to be more comprehensive.
3. The data on the program's boundaries need to be revised.

4. Data on the program's behavior needs to be completed.

In our social, economic, and space research efforts, it is not uncommon to encounter missing data. For example, it is challenging in agricultural production to precisely predict the output and the resulting economic values due to uncertainties in areas such as labor quality, natural environments, weather conditions, and commodity markets.

The grey system might influence the overcoming techniques, including partially known knowledge and unknown information.

Regarding the vagueness and ambiguity inherent in human decision making, a grey theory has extensive applications in supplier selection under MCDM. This research uses grey theory to address the ambiguity inherent in human decision making. The following section describes the context of two methodologies used in the proposed framework.

3.2. FUCOM (Full Consistency Method)

Pamučar [37] introduced FOCUM as a novel and practical approach for determining the criterion's weight. This methodology might reduce the inconsistency between the many comparisons made by decision makers. A list of specific advantages of this approach is provided below:

(1) FUCOM provides the ability to assess appropriate weight coefficients using the reliability of the results; (2) by using FUCOM, the best weight coefficient values can be found using a straightforward mathematical method, allowing for the prioritization of particular criteria when analyzing processes in response to the needs of decision makers at the time and reducing the risks associated with decision making; (3)FUCOM offers the best weight-value increases with the least amount of subjectivity and effect of inconsistent expert preferences on the actual output of the values of the criteria; (4) it is just necessary to compare the criteria n times; (5) the concept is adaptable and appropriate for use with various measurement items that reflect specialist judgments.

This method has been used in the locations described in the following section. This approach for assessing the logistics of express mail was created in 2018 by Prentkovskis et al. [38]. In the first stage, the criteria were ranked using the Delphi approach. After that, they used FUCOM to determine the weight of each standard. Lastly, they use service quality to identify the disparity between the perception and expectation of the criterion. A separate study used a FUCOM-MABAC (Full Consistency Method-Multi-Attributive Border Approximation and Comparison) method to choose and rank the manufacturer [39]. Also, a technique combining FUCOM and the Rough Range of Value (RROV) was established to select and assess the AGVs in the warehouse [40]. Similarly, the Full Consistency Method and Multi-Attributive Ideal-Real Comparative Analysis techniques were created to evaluate a level-crossing model that must be protected for ten alternatives in Serbia [41]. In addition, FUCOM and AHP were used to evaluate airlines' performance in LIBYAN to rank them in order to improve performance in the future for each firm.

In conclusion, the study demonstrated the superior performance of FUCOM over AHP for rating alternatives [42]. Matić et al. [43] investigated FUCOM and rough COPRAS for a hybrid strategy for sustainable supplier selection using the DOMBI aggregator. They compared the fuzzy and crisp MABAC findings for designing a single-span bridge using FUCOM to determine the criterion's weight and establish a hybrid technique combining FUCOM-TOPSIS and FUCOM-MABAC for determining the optimal hazardous material delivery routes and identifying the most dangerous sections of roads to enhance traffic management and safety. In Table 1, we have categorized some of the research that used the FUCOM method.

Table 1. Some existing research based on FUCOM.

Authors (Year)	Procedure
Ibrahim Badi-Ali Abdulshahed (2019) [42]	FUCOM-AHP
Olegas Prentkovskis et al. (2018) [38]	Delphi-FUCOM-SERVQUAL
Bojan Matić et al. (2019) [43]	FUCOM-Rough COPRAS using rough Dombi aggregator
Darko Božanić et al. (2019) [44]	FUCOM—fuzzy MABAC
Zdravko Nunić (2018) [39]	FUCOM-MABAC
Mohammad Noureddine, Milos Ristic (2019) [45]	FUCOM-TOPSIS-MABAC
Dragana Nenadić (2019) [46]	FUCOM_WASPAS
Edmundas Kazimieras Zavadskas et al. (2018) [40]	FUCOM-R_ROV
Živko Erceg, Fatima Mularifović (2019) [47]	FUCOM-WASPAS
Hamed Fazlollahtabar et al. (2019) [48]	FUCOM_WASPAS
Dragan Pamučar et al. (2018) [41]	FUCOM-MAIRCA
Elmina Durmić (2019)[49]	FUCOM

3.3. PROMTHEE II

Brans and Mareschal [50] created the PROMETHEE (Preference Ranking Organization Tool for Enrichment Evaluation) as an MCDM method. Compared to other strategies used for multi-criteria analysis, this ordering method could be more complex to conceptualize and implement. It is perfectly adapted for situations where a small variety of options must be ranked based on several contradicting factors. Numerous researchers have adapted PROMETHEE's methodologies to decision-making issues with great success in various domains. The PROMETHEE approaches satisfy the specific requirements of a suitable multi-criteria method, and their success is attributable mainly to their mathematical features and user-friendliness.

4. Methodology

This research utilizes a case study methodology. Agricultural managers from an Iranian wheat and barley seed production organization are used in this investigation. These managers examine and choose an appropriate supplier depending on the supplier's degree of social sustainability implementation. In this section, we first discuss hypothesis generation and research limitations and then describe the methodology and instruments used to conduct this assessment.

4.1. Hypothesis Development and Research Challenges

The proposed hybrid methodology uses FUCOM and PROMTHEE based on Grey Theory to tackle the vagueness of human judgment and to evaluate the performance of wheat and barley seed production companies from a social sustainability point of view. The motivation behind this study stems from the fact that several times a year, the seed users, especially the farmers, need to receive clear information about the suppliers' performance from various perspectives, and due to the increasing importance of social sustainability in emerging economies, we intend to overlook this periodic challenge and provide understandable and unambiguous information about the ranking of wheat and barley seed production companies from a social aspect. To tackle the vagueness and ambiguity of human judgment, we employed our methodology based on Grey Interval Number. Also, this strategy's data collection method is based on interviews with experts. Also, the experts' weights have been prioritized based on their experiences. Therefore, the hypothesis of our research can be defined as follows.

Possible Hypothesis: Using a hybrid grey decision methodology will improve the effectiveness and accuracy of socially sustainable supplier selection compared to traditional decision-making approaches. Also, implementing the grey interval number method will result in a more accurate and reliable assessment of the uncertainty and ambiguity inherent to subjective judgment in this investigation compared to conventional approaches.

Several concepts may provide the philosophy underpinning the application of a hybrid grey decision methodology in socially sustainable supplier selection. Listed below are several potential philosophies that might influence this approach:

1. Merging multiple perspectives: This philosophy could highlight the significance of contemplating multiple criteria and approaches when selecting suppliers, and by employing a combination of techniques, the technique endeavors to consider qualitative and quantitative variables, allowing for a more thorough assessment of suppliers than is possible with conventional methods based solely on numbers.
2. Addressing uncertainty: This philosophy may recognize that supplier selection decision-making processes frequently contain inherent ambiguity and inaccurate datasets. The hybrid grey decision technique intends to address this difficulty by employing the grey concept of systems, which aims to deal with ambiguous and insufficient information, thereby improving the decision-making process in supplier selection.
3. Supporting social sustainability: This philosophy might emphasize social sustainability in supplier selection, acknowledging the importance of considering social and ethical factors in addition to conventional financial variables. The approach demonstrates its dedication to ethical procurement practices, equitable worker conditions, volunteering, and other facets of corporate social responsibility by incorporating social sustainability criteria into the decision-making process.
4. Balancing objectivity and subjectivity: This philosophy may balance objective criteria (performance metrics and quality measures) and personal variables (stakeholders' opinions and supplier relationships). Recognizing that supplier selection decisions entail statistical analysis and personal assessment, a hybrid grey decision methodology that incorporates both variables could be developed.
5. Constant improvement and responsiveness: This supplier selection theory could highlight the need for perpetual enhancement and flexibility. This philosophy could be aligned with the hybrid grey decision methodology by offering an adaptable framework that permits modifications and improvements based on suggestions, expanding the criteria for sustainability and changing business requirements.

This study contributes by presenting a novel technique that uses the Grey FUCOM and Grey PROMTHEE methodologies to assess the social sustainability of a particular enterprise in the agriculture sector of developing economies. The study intends to guide seed users in identifying essential requirements and effective suppliers for ecological sustainability, ultimately promoting healthier communities and improving assessment methods in the initial phases of the food supply chain by addressing the shortage of attention devoted to social sustainability in supplier selection.

This research also contains some limitations. Some potential limitations of the work include the followings:

1. Limited generalizability: The research results and suggested method may not be pertinent to industries or territories outside the emergent economy nations' agricultural industry.
2. Exclusion of a multi-stakeholder viewpoint: The examination procedure needs multiple stakeholders, which may reduce the assessment's comprehensiveness and precision.
3. The absence of information on sample size and data representativeness makes it challenging to assess the external reliability of the results due to a lack of information on the sample size and data representation.

4.2. Grey Interval Number

Grey system theory [51] is an approach for modeling systems with unclear knowledge that has widespread use for addressing vagueness and ambiguity in human decision making.

We based our methods on the Grey Interval Number (GIN) to address the vagueness and ambiguity of human judgment in this research. The definitions and operations of interval grey numbers include the following:

Definition 1. An interval grey number $\otimes a \in [\underline{a},\ \overline{a}]$ is characterized as a range with identified lower $\underline{a}$ and upper $\overline{a}$ bounds, while there are no knowledge of distribution, shown as:

$$\otimes a \in [\underline{a},\ \overline{a}] = [\acute{a}\ \in a\ |\underline{a}\ \leq\ \acute{a}\ \leq \overline{a}], \tag{1}$$

where $\underline{a}$ and $\overline{a}$ are the absolute lowest and most significant values, respectively. If $\underline{a} = \overline{a}$ then the interval grey number $\otimes a$ is reduced to a crisp number.

Definition 2. Assume that $\otimes a \in [\underline{a},\ \overline{a}]$ and $\otimes b \in \left[\underline{b}, \overline{b}\right]$ are two interval grey numbers. The following relationships define the essential mathematical operation of the interval grey number:

$$\otimes a + \otimes b\ \in \left[\underline{a} + \underline{b},\ \overline{a} + \overline{b}\right]. \tag{2}$$

$$\otimes a - \otimes b\ \in \left[\underline{a} - \overline{b},\ \overline{a} - \underline{b}\right]. \tag{3}$$

$$\otimes a \times \otimes b\ \in \left[\min\left(\underline{a}\,\underline{b},\ \underline{a}\,\overline{b},\ \overline{a}\,\underline{b},\ \overline{a}\overline{b}\right),\ \max\left(\underline{a}\,\underline{b},\ \underline{a}\,\overline{b},\ \overline{a}\,\underline{b},\ \overline{a}\overline{b}\right)\right]. \tag{4}$$

$$\otimes a \div \otimes b \in \left[\min\left(\frac{\underline{a}}{\underline{b}},\ \frac{\underline{a}}{\overline{b}},\ \frac{\overline{a}}{\underline{b}},\ \frac{\overline{a}}{\overline{b}}\right),\ \max\left(\frac{\underline{a}}{\underline{b}},\ \frac{\underline{a}}{\overline{b}},\ \frac{\overline{a}}{\underline{b}},\ \frac{\overline{a}}{\overline{b}}\right)\right]. \tag{5}$$

Definition 3. Consider that k belongs to the set of real numbers, $k \in \mathbb{R}$. The following equations do the operation of multiplying and dividing the interval grey number by k:

$$k \times \otimes a\ \ \in k \times\ [\underline{a},\ \overline{a}] = \begin{Bmatrix} If\ k\ \geq 0,\ then\ \ \mathrm{k} \times \otimes a = [k\underline{a},\ k\overline{a}] \\ If\ k < 0,\ then\ \ \mathrm{k} \times \otimes a = [k\overline{a},\ k\underline{a}] \end{Bmatrix}. \tag{6}$$

$$\frac{1}{k}\ \otimes a = \begin{Bmatrix} If\ \ k\ \geq 0,\ then\ \frac{1}{k} \times [\underline{a},\ \overline{a}\,] = \left[\frac{\underline{a}}{k}, \frac{\overline{a}}{k}\right] \\ If\ k < 0,\ then\ \frac{1}{k} \times [\underline{a},\ \overline{a}\,] = \left[\frac{\overline{a}}{k},\ \frac{\underline{a}}{k}\right] \end{Bmatrix}. \tag{7}$$

4.3. FUCOM Method

This section introduces the steps required for constructing the model based on FUCOM to obtain the criteria' weight coefficients.

Step 1: Each decision maker intends to rate the parameters from the predetermined list of criteria in the first stage. Therefore, based on the expected weight coefficients of the requirements, they rank them from the most to least important criteria.

$$C_{j(1)} > C_{j(2)} > \ldots > C_{j(k)}, \tag{8}$$

where k stands for the measured criterion's rank when two or more criteria are judged to exist and have equal weight, and the equality sign is used in the phrase instead of the symbol ">" among these criteria (8).

Step 2: An evaluation of the base classifiers is done in the second step, and the relative precedence ($\varphi_{k/k+1}$, $k = 1, 2, \ldots, n$, where k indicates the order of the requirements) is established for the assessment criterion.

$$\Phi = \left(\varphi_{1/2},\ \varphi_{2/3}, \ldots, \varphi_{k/(k+1)}\right). \tag{9}$$

Every judgment compares the criteria and determines the importance of each criterion in the statement, considering a specified level for the evaluating factors (8). In this way, the orders proposed by each judge have been compared concerning the highest-ranked (the most crucial) criteria. Consequently, the importance of the criterion ($\overline{\varpi}_{C_{j(k)}}$) was achieved for each of the parameters specified in Step 1. The top criteria are evaluated against themselves ($\overline{\varpi}_{C_{j(1)}=1}$). Consequently, the $n - 1$ evaluation of the criterion must be conducted.

Step 3: By considering the fulfillment of the following two requirements, the output results of the criteria weights for all components could be calculated as follows:

(1) The proportion of criteria weights is proportional to the relative importance of the detected criteria ($\varphi_{k/(k+1)}$) defined in Step 2, i.e., that the following condition is met:

$$\frac{\sqsupseteq_k}{\sqsupseteq_{k+1}} = \varphi_{k/(k+1)}. \tag{10}$$

(2) The weight coefficients' final values should satisfy the mathematical transitivity condition. If $\varphi_{k/(k+1)} = \frac{\sqsupseteq_k}{\sqsupseteq_{k+1}}$ and $\varphi_{(k+1)/(k+2)} = \frac{\sqsupseteq_{k+1}}{\sqsupseteq_{k+2}}$, then the weight coefficients of the evaluation criteria need to meet the following:

$$\frac{\sqsupseteq_k}{\sqsupseteq_{k+2}} = \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)}. \tag{11}$$

In this manner, the model could satisfy the minimum deviation from consistency (DFC (§) = 0). This is a requirement for maximum thickness to be fulfilled. Therefore, the final model for the FOCOM method is presented as follows:

$$\begin{aligned}
&\text{Min§}, \\
&\text{s.t.}, \\
&\left|\frac{\sqsupseteq_{j(k)}}{\sqsupseteq_{j(k+1)}} - \varphi_{k/(k+1)}\right| \le \text{§},\ \forall j, \\
&\left|\frac{\sqsupseteq_{j(k)}}{\sqsupseteq_{j(k+2)}} - \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)}\right| \le \text{§},\ \forall j, \\
&\textstyle\sum_{j=1}^{n} \sqsupseteq_j = 1,\ \forall j,\ \sqsupseteq_j \ge 0,\ \forall j.
\end{aligned} \tag{12}$$

The final values for the weight coefficients are obtained by solving the model (12), which is $(\sqsupseteq_1,\ \sqsupseteq_2, \ldots,\ \sqsupseteq_n)^T$, and following that, DFC (χ) is generated.

4.4. Grey-Based PROMTHEE II Method

In this section, we recall Grey-Based PROMTHEE II, which will be used to rank the alternatives according to each DM's preference information. We use the criteria's weights obtained through the Grey–Based FUCOM method. The main steps of Grey-Based PROMTHEE II can be described as follows:

In the grey-PROMTHEE method, initially consider $A_i \in \{A_i \mid i = 1, \ldots, n\}$ as the n alternatives, $C_j \in \{C_j \mid j = 1, \ldots, m\}$ as the m criteria, $w_j \in \{w_j \mid j = 1, \ldots, m\}$ as criterion j's weight, and $DM_z \in \{DM_z \mid z = 1, \ldots, k\}$ as the k decision makers. The assigned performance score for an alternative i concerning a criterion j by decision maker z is represented by $\otimes PS_{ij}^z$. The Grey-based PROMTHEE II method has the following steps:

Step 1: Create the performance matrix for each DM. In this step, the DMs assign the performance score $\otimes PS_{ij}^z$ using Table 2 and according to the following Table 3:

Table 2. Linguistic judgments and their corresponding interval grey number.

Scale	**Grey Interval Number**
Very Very Bad (VVB)	[0, 1]
Very Bad (VB)	[1, 2]
Bad (B)	[2, 3]
Medium Bad (MB)	[3, 4]
Fair (F)	[4, 5]
Medium Good (MG)	[5, 6]
Good (G)	[6, 7]
Very Good (VG)	[7, 8]
Very Very Good (VVG)	[8, 9]
Extremely Good (EG)	[9, 10]

Table 3. Grey-Based Performance Matrix by DMs.

		Criteria				
		C_1	C_2	C_j	…	C_m
Alternative	A_1	$\otimes PS_{11}^z$	$\otimes PS_{12}^z$	$\otimes PS_{1j}^z$	…	$\otimes PS_{1m}^z$
	A_2	$\otimes PS_{21}^z$	$\otimes PS_{22}^z$	$\otimes PS_{2j}^z$	…	$\otimes PS_{2m}^z$
	A_i	$\otimes PS_{i1}^z$	$\otimes PS_{i2}^z$	$\otimes PS_{ij}^z$	…	$\otimes PS_{im}^z$
	…	…	…	…	…	…
	A_n	$\otimes PS_{n1}^z$	$\otimes PS_{n2}^z$	$\otimes PS_{nj}^z$	…	$\otimes PS_{nm}^z$
Aggregated Grey-Based Performance Matrix						
		Criteria				
		C_1	C_2	C_j	…	C_m
Alternatives	A_1	$\otimes PS_{11}$	$\otimes PS_{12}$	$\otimes PS_{1j}$	…	$\otimes PS_{1m}$
	A_2	$\otimes PS_{21}$	$\otimes PS_{22}$	$\otimes PS_{2j}$	…	$\otimes PS_{2m}$
	A_i	$\otimes PS_{i1}$	$\otimes PS_{i2}$	$\otimes PS_{ij}$	…	$\otimes PS_{im}$
	…	…	…	…	…	…
	A_n	$\otimes PS_{n1}$	$\otimes PS_{n2}$	$\otimes PS_{nj}$	…	$\otimes PS_{nm}$
Normalized Aggregated Grey-based Performance Matrix						
		Criteria				
		C_1	C_2	C_j	…	C_m
Alternatives	A_1	$\otimes \widetilde{PS}_{11}$	$\otimes \widetilde{PS}_{12}$	$\otimes \widetilde{PS}_{1j}$	…	$\otimes \widetilde{PS}_{1m}$
	A_2	$\otimes \widetilde{PS}_{21}$	$\otimes \widetilde{PS}_{22}$	$\otimes \widetilde{PS}_{2j}$	…	$\otimes \widetilde{PS}_{2m}$
	A_i	$\otimes \widetilde{PS}_{i1}$	$\otimes \widetilde{PS}_{i2}$	$\otimes \widetilde{PS}_{ij}$	…	$\otimes \widetilde{PS}_{im}$
	…	…	…	…	…	…
	A_n	$\otimes \widetilde{PS}_{n1}$	$\otimes \widetilde{PS}_{n2}$	$\otimes \widetilde{PS}_{nj}$	…	$\otimes \widetilde{PS}_{nm}$

Step2: Aggregate the performance scores of alternatives concerning the criteria for all decision makers based on the following Formula (13) and create Table 3:

$$\otimes PS_{ij} = \otimes Performance\ score(Alternative\ i,\ criterion\ j) = \sum_{z=1}^{k} w'_z \times PS_{ij}^z. \tag{13}$$

Step3: Normalize the aggregated grey-based performance matrix in the previous step by using the following Formula (14), and create the normalized performance matrix of alternatives concerning the criteria according to Table 3:

$$\otimes\widetilde{PS}_{ij} = \frac{\otimes PS_{ij}}{\max_{i=1}^{i=n}\overline{PS}_{ij}}. \tag{14}$$

Step 4: Rank alternatives using the PROMTHEE II method (steps 4 to 8). Initially, calculate the deviation of the normalized aggregated performance of alternative A_Q from A_R on criterion *j* for each pair of alternatives using Formula (15):

$$dv_j(A_Q, A_R) = \frac{\overline{PS}_{Qj} - \underline{PS}_{Rj}}{\left|\overline{PS}_{Qj} - \underline{PS}_{Qj}\right| + \left|\overline{PS}_{Rj} - \underline{PS}_{Rj}\right|}. \tag{15}$$

Step 5: Calculate the preference degree of alternatives A_Q over A_R on criterion j using the following Formula (16):

$$PD_j(A_Q, A_R) = \left\{\begin{array}{cc} 0 & if\ dv_j(A_Q, A_R) \le 0 \\ dv_j(A_Q, A_R) & if\ \ 0 < dv_j(A_Q, A_R) < 1 \\ 1 & if\ \ dv_j(A_Q, A_R) \ge 1 \end{array}\right\}. \tag{16}$$

Step 6: Calculate the relative preference of A_Q over A_R using Formula (17) for each pair of alternatives. In the Formula (17), the weight of the criteria obtained using the Grey FOCUM method is defined in Section 4.2.

$$\pi(A_Q, A_R) = \sum_{j=1}^{j=m} PD_j(A_Q,\ A_R) \times w_j. \tag{17}$$

Step 7: Rank the alternatives based on the value of net flow $\widetilde{\varnothing}(A_i)$ obtained by measuring the intensity of the preference for one alternative over all the others. In the following Formula (18), $\widetilde{\varnothing}^{+}(A_Q)$ represents the outflow of A_Q, a measure of the preference for A_Q over all the other alternatives. $\widetilde{\varnothing}^{-}(A_Q)$ represents the inflow of A_Q, a measure of the preference for the other alternatives as a group over alternative A_Q.

$$\widetilde{\varnothing}(A_Q) = \widetilde{\varnothing}^{+}(A_Q) - \widetilde{\varnothing}^{-}(A_R) = \frac{1}{n-1} \sum_{\substack{R=1 \\ Q \ne R}}^{n} \pi(A_Q, A_R) - \frac{1}{n-1} \sum_{\substack{R=1 \\ Q \ne R}}^{n} \pi(A_R, A_Q). \tag{18}$$

Step 8: Arrange the obtained $\widetilde{\varnothing}(A_Q)$ values for all alternatives in descending order. The higher the obtained $\widetilde{\varnothing}(A_Q)$ value, the more priority will be assigned to the considered alternative.

4.5. The Framework of Proposed Methodology

An integrated framework of the proposed methodology has been presented in this section (Figure 1).

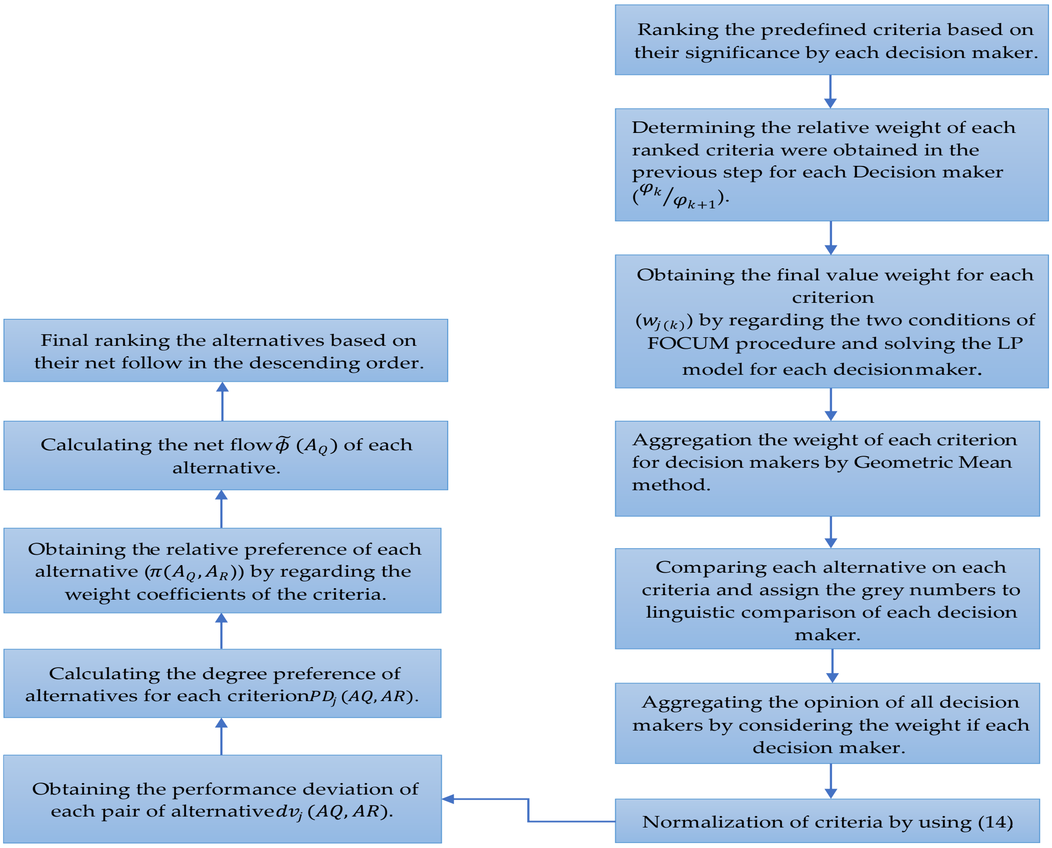

Figure 1. The integrated framework for the proposed methodology.

5. Case Study

The first step for an effective and healthy food supply chain is having reliable and qualified suppliers in the supply chain. Regarding this fact, selecting the best suppliers using an efficient decision support tool is crucial. As a result, this section presents a hybrid method based on Grey-FUCOM and Grey-PROMATHEE II to have a consistent judgment that could precisely include the uncertainty and vagueness of the opinion of experts.

According to the reports, the average wheat production in Iran in 1989–1992 was about 8 million tons, compared to 11 million tons produced in 2012–2016. On the other hand, based on long-term standards, wheat (200 kg per capita) has persistently dominated the food basket of Iranians. This shows the increasing importance of the quality and evaluation of wheat and barley seed suppliers.

The criteria considered in this research were finalized based on interviews with experts and managers in evaluating seed, barley, and wheat production companies.

The five-expert panel that participated in this research determined the weight coefficients of the criteria and evaluated the alternatives. The business selected experts with 5, 8, 11, 15, and 19 years of expertise evaluating seed companies. After conducting the expert interviews, the data were processed to compile the collective professional opinion. Data collection for the 2022 growing season occurred between December 2021 and July 2022.

5.1. Using Grey-FUCOM to Obtain the Weights of Criteria

Step 1: In this step, each decision maker ranked the criteria according to their preferences from most to least important. The preference ranking of the experts is shown in Table 4.

Table 4. The preferences ranking of DMs for criteria.

No. Expert	Years of Experience	Preferences Ranking
DM1	19	$C_6 = C_5 > C_3 > C_1 > C_2 > C_4$
DM2	8	$C_3 > C_5 > C_6 > C_4 = C_1 > C_2$
DM3	5	$C_6 > C_5 = C_1 > C_3 > C_4 > C_2$
DM4	15	$C_1 > C_6 > C_5 > C_3 > C_4 = C_2$
DM5	11	$C_6 = C_5 > C_1 > C_2 > C_3 > C_4$

Step 2: In this step, each decision maker compared the ranked criteria from the previous step with the first-ranked in their preferences ranking. To this end, the linguistic scales and grey interval numbers assigned to each linguistic level were used to avoid vagueness in the experts' opinion based on Table 5. Therefore, the importance of the ranking criteria was obtained and shown in Table 6.

Table 5. The Linguistic variable and its related Grey number.

Linguistic Variables	Grey Interval Numbers
Very poor	[1, 2]
Poor	[3, 4]
Fair	[5, 6]
Good	[7, 8]
Very good	[9, 10]

Table 6. The Importance of the ranked criteria.

<table>
<tr><td colspan="7">DM_1</td></tr>
<tr><td rowspan="2">Criteria importance ($\overline{\varpi}_{C_{j(k)}}$)</td><td>$C_6$</td><td>$C_5$</td><td>$C_3$</td><td>$C_1$</td><td>$C_2$</td><td>$C_4$</td></tr>
<tr><td>1</td><td>1</td><td>1.33</td><td>1.6</td><td>2.66</td><td>4</td></tr>
<tr><td colspan="7">DM_2</td></tr>
<tr><td rowspan="2">Criteria importance ($\overline{\varpi}_{C_{j(k)}}$)</td><td>$C_3$</td><td>$C_5$</td><td>$C_6$</td><td>$C_4$</td><td>$C_1$</td><td>$C_2$</td></tr>
<tr><td>1</td><td>1.4</td><td>1.75</td><td>2.33</td><td>2.33</td><td>3.5</td></tr>
<tr><td colspan="7">DM_3</td></tr>
<tr><td rowspan="2">Criteria importance ($\overline{\varpi}_{C_{j(k)}}$)</td><td>$C_6$</td><td>$C_1$</td><td>$C_5$</td><td>$C_3$</td><td>$C_4$</td><td>$C_2$</td></tr>
<tr><td>1</td><td>1.14</td><td>1.14</td><td>1.6</td><td>2</td><td>2.66</td></tr>
<tr><td colspan="7">DM_4</td></tr>
<tr><td rowspan="2">Criteria importance ($\overline{\varpi}_{C_{j(k)}}$)</td><td>$C_1$</td><td>$C_6$</td><td>$C_5$</td><td>$C_3$</td><td>$C_2$</td><td>$C_4$</td></tr>
<tr><td>1</td><td>1.125</td><td>1.29</td><td>1.8</td><td>2.25</td><td>2.25</td></tr>
<tr><td colspan="7">DM_5</td></tr>
<tr><td rowspan="2">Criteria importance ($\overline{\varpi}_{C_{j(k)}}$)</td><td>$C_6$</td><td>$C_5$</td><td>$C_1$</td><td>$C_2$</td><td>$C_3$</td><td>$C_4$</td></tr>
<tr><td>1</td><td>1</td><td>1.28</td><td>1.8</td><td>2.25</td><td>3</td></tr>
</table>

Based on the Expressions (9)–(11), which have been mentioned in Section 4.2 and used in solving the Model (12), the weight coefficients of the criteria are estimated. Because there are five experts to evaluate the criteria, the final FUCOM model for each expert was solved by GAMS win64, which is presented as follows:

DM_1: $\min \chi$
$S.t.$
$\left|\frac{w_6}{w_5}-1\right| \leq \chi \left|\frac{w_5}{w_3}-1.33\right| \leq \chi \left|\frac{w_3}{w_1}-1.2\right| \leq \chi, \left|\frac{w_1}{w_2}-1.66\right| \leq \chi \left|\frac{w_2}{w_4}-1.5\right| \leq \chi \left|\frac{w_6}{w_3}-1.33\right| \leq \chi,$
$\left|\frac{w_5}{w_1}-1.6\right| \leq \chi \left|\frac{w_3}{w_2}-1.99\right| \leq \chi \left|\frac{w_1}{w_4}-2.49\right| \leq \chi, \sum_{w=1}^{6} w_j = 1\ w_j \geq 0, \forall j.$

DM_2: $\min \chi$
$S.t.$
$\left|\frac{w_3}{w_5}-1.4\right| \leq \chi, \left|\frac{w_5}{w_6}-1.25\right| \leq \chi, \left|\frac{w_6}{w_4}-1.33\right| \leq \chi, \left|\frac{w_4}{w_1}-1\right| \leq \chi, \left|\frac{w_1}{w_2}-1.5\right| \leq \chi, \left|\frac{w_3}{w_6}-1.75\right| \leq \chi,$
$\left|\frac{w_5}{w_4}-1.66\right| \leq \chi, \left|\frac{w_6}{w_1}-1.33\right| \leq \chi, \left|\frac{w_4}{w_2}-1.5\right| \leq \chi, \sum_{w=1}^{6} w_j = 1, w_j \geq 0, \forall j.$

DM_3: $\min \chi$
$S.t.$
$\left|\frac{w_6}{w_1}-1.14\right| \leq \chi, \left|\frac{w_1}{w_5}-1\right| \leq \chi, \left|\frac{w_5}{w_3}-1.4\right| \leq \chi, \left|\frac{w_3}{w_4}-1.25\right| \leq \chi, \left|\frac{w_4}{w_2}-1.33\right| \leq \chi, \left|\frac{w_6}{w_5}-1.14\right| \leq \chi,$
$\left|\frac{w_1}{w_3}-1.4\right| \leq \chi, \left|\frac{w_5}{w_4}-1.75\right| \leq \chi, \left|\frac{w_3}{w_2}-1.66\right| \leq \chi, \sum_{w=1}^{6} w_j = 1, w_j \geq 0, \forall j.$

DM_4: $\min \chi$
$S.t.$
$\left|\frac{w_1}{w_6}-1.12\right| \leq \chi, \left|\frac{w_6}{w_5}-1.14\right| \leq \chi, \left|\frac{w_5}{w_3}-1.4\right| \leq \chi, \left|\frac{w_3}{w_2}-1.25\right| \leq \chi, \left|\frac{w_2}{w_4}-1\right| \leq \chi, \left|\frac{w_1}{w_5}-1.3\right| \leq \chi,$
$\left|\frac{w_6}{w_3}-1.61\right| \leq \chi, \left|\frac{w_5}{w_2}-1.75\right| \leq \chi, \left|\frac{w_3}{w_4}-1.25\right| \leq \chi, \sum_{w=1}^{6} w_j = 1, w_j \geq 0, \forall j.$

DM_5: $\min \chi$
$S.t.$
$\left|\frac{w_6}{w_5}-1\right| \leq \chi, \left|\frac{w_5}{w_1}-1.28\right| \leq \chi, \left|\frac{w_1}{w_2}-1.41\right| \leq \chi, \left|\frac{w_2}{w_3}-1.25\right| \leq \chi, \left|\frac{w_3}{w_4}-1.33\right| \leq \chi,$
$\left|\frac{w_6}{w_1}-1.28\right| \leq \chi, \left|\frac{w_5}{w_2}-1.8\right| \leq \chi, \left|\frac{w_1}{w_3}-1.76\right| \leq \chi, \left|\frac{w_2}{w_4}-1.66\right| \leq \chi, \sum_{w=1}^{6} w_j = 1, w_j \geq 0, \forall j.$

Based on the results obtained from solving the linear programming models, the weight coefficients of each expert will be calculated and shown in Table 7. Finally, these weighting variables will be utilized in the subsequent phase to determine the final grade of the firm producing wheat and barley seeds using the Grey-PROMATHEE II technique.

Table 7. Weight coefficient.

	C_1	C_2	C_3	C_4	C_5	C_6	χ
DM_1	0.156	0.094	0.188	0.063	0.25	0.249	0.001
DM_2	0.125	0.084	0.291	0.125	0.208	0.167	0.006
DM_3	0.206	0.089	0.147	0.118	0.206	0.235	0.005
DM_4	0.245	0.108	0.135	0.107	0.189	0.217	0.003
DM_5	0.190	0.135	0.108	0.081	0.243	0.243	0.008
Average value	0.184	0.102	0.1738	0.0988	0.2192	0.2222	

5.2. Ranking Alternative by Grey-PROMATHEE II

Assume that the case study contains five decision makers (DM), six social criteria (C), and five alternatives (A). We assigned the weight to each DM based on their working experience in the proposed methodology. The more the work experience, the more weight will be assigned to DM. The DM's importance is shown in Table 8.

Table 8. DM's weight.

Expert Number	Working Experience (Year)	DM's Weight	DM's Weight
Decision makers 1	19	0.327	19/58
Decision makers 2	8	0.138	8/58
Decision makers 3	5	0.086	5/58
Decision makers 4	15	0.259	15/58
Decision makers 5	11	0.190	11/58

The social criteria which have been selected in this study, along with the brief description, have been demonstrated in Table 9.

Table 9. Social Criteria.

Criteria	Description
Work health and safety (C1)	This pertains to the companies' emphasis on their procedures and the safety and health practices used by a prospective vendor.
Occupational health and safety management system (C2)	This pertains to the well-being and health of employees during their time at the office.
Training education and community influence (C3)	This pertains to the transmission and influence of a company's information on its staff and the society in which they exist.
The interests and rights of employees (C4)	This relates to elements that foster concerns and associated problems of economic opportunities.
Information disclosure (C5)	This pertains to companies giving their clients and consumers useful details on the mechanical applications in the production line.
Contractual stakeholders' influence (C6)	This pertains to the degree of consideration a prospective provider devotes to including its customers in its activities.

Five of the largest wheat and barley seed producers in Golestan province, Iran, have been selected in this case study. More details about them have been provided in Table 10.

Table 10. A description of wheat and barley seed producers in Golestan.

Supplier	Location (City)	Year of Establishment
S 1	Gorgan	1988
S 2	Minoodasht	2001
S 3	Gonbad	2004
S 4	Bandar-e Torkman	1998
S 5	Kordkuy	2009

In the first step, each DM presents a matrix according to the linguistics variable in Table 2, shown in Section 4.3. The DM's evaluation of each alternative concerning each criterion has been presented in Table 11. Then, they translated to the interval grey number using Table 2.

Table 11. Performance matrix by different decision makers.

DM 1	C1	C2	C3	C4	C5	C6
A1	MG	G	MG	G	MG	G
A2	MB	MB	MB	G	MG	G
A3	VG	G	G	MG	MG	MG
A4	G	VVG	VVG	VVG	VG	VG
A5	G	VG	VVG	G	G	G
DM 2	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**
A1	VG	MB	MB	F	F	VG
A2	MG	F	VB	VB	B	MG
A3	G	MG	MB	MB	G	MG
A4	F	F	MB	MB	MG	G
A5	G	F	F	MB	MG	F
DM 3	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**
A1	F	VG	F	MB	VG	MB
A2	B	MB	MG	B	MB	MB
A3	F	VG	MG	F	MB	MG
A4	F	G	MG	F	G	VVG
A5	MG	F	MB	MG	MB	F
DM 4	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**
A1	MG	MG	G	G	F	VVG
A2	F	MG	F	MB	VG	VG
A3	G	F	F	MB	VG	VG
A4	MG	VG	G	MG	VVG	VG
A5	F	VG	VG	EG	EG	F
DM 5	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**
A1	MB	F	F	MB	G	MB
A2	MB	B	B	MG	G	MG
A3	VVG	G	MG	G	MB	MB
A4	MG	MB	F	MB	VG	G
A5	VG	G	E	G	MG	MG

DM = Decision maker, C = Criteria.

In this step, by using Formula (13), the DMs' performance matrixes are aggregated. The aggregated performance matrix has been presented in Table 12.

The aggregated Grey-Based Performance Matrix is normalized in the next step using Formula (12). The Normalized Aggregated Grey-based Performance Matrix is also shown in Table 12.

After normalizing the aggregated Grey-based Performance Matrix, the performance rating dispersion of the alternative A_Q from A_R on each criterion is calculated using Formula (15). The results have been presented for each alternative in Table 13.

Table 12. Aggregated Grey-Based Performance Matrix.

	C1		C2		C3		C4		C5		C6	
	L	**U**	**L**	**U**	**L**	**U**	**L**	**U**	**L**	**U**	**L**	**U**
A1	4/81	5/81	5/033	6/033	4/707	5/707	4/896	5/896	4/965	5/965	5/828	6/828
A2	4/757	8/585	3/466	4/466	2/965	3/965	3/345	4/345	4/795	5/795	6	7
A3	6/535	14/83	5/43	6/43	4/792	5/792	4/31	5/31	5/104	6/104	5/138	6/138
A4	5/103	6/103	6/067	7/067	5/774	6/774	5/239	6/239	6/897	7/897	6/758	7/758
A5	5/586	6/586	6/138	7/138	6/949	7/949	6/277	7/277	6/191	7/191	4/844	5/844
Normalized Aggregated Grey-based Performance Matrix												
	C1		**C2**		**C3**		**C4**		**C5**		**C6**	
	L	**U**	**L**	**U**	**L**	**U**	**L**	**U**	**L**	**U**	**L**	**U**
A1	0/324	0/392	0/705	0/845	0/592	0/718	0/673	0/810	0/629	0/755	0/751	0/880
A2	0/321	0/579	0/486	0/626	0/373	0/499	0/460	0/597	0/607	0/734	0/773	0/902
A3	0/441	1/000	0/761	0/901	0/603	0/729	0/592	0/730	0/646	0/773	0/662	0/791
A4	0/344	0/412	0/850	0/990	0/726	0/852	0/835	0/857	0/873	1/000	0/871	1/000
A5	0/377	0/444	0/860	1/000	0/874	1/000	0/863	1/000	0/784	0/911	0/624	0/753

C = Criteria, A = Alternative, L = Lower, U = Upper.

Table 13. $dv_j(A_Q, A_R)$ for different alternatives.

Alternative 1	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**
(A1, A2)	0/218	1/284	1/371	1/276	0/585	0/414
(A1, A3)	−0/078	0/302	0/458	0/793	0/431	0/845
(A1, A4)	0/354	−0/017	−0/034	−0/152	−0/466	0/035
(A1, A5)	0/112	−0/052	−0/621	−0/191	−0/113	0/992
Alternative 2	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**
(A2, A1)	0/782	−0/284	−0/371	−0/276	0/415	0/586
(A2, A3)	0/169	−0/482	−0/414	0/018	0/346	0/931
(A2, A4)	0/721	−0/801	−0/905	−1/483	−0/551	0/121
(A2, A5)	0/621	−0/836	−1/492	−0/966	−0/198	1/078
Alternative 3	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**
(A3, A1)	0/543	0/699	0/543	0/207	0/570	0/155
(A3, A2)	1/414	1/482	1/414	0/983	0/655	0/069
(A3, A4)	0/009	0/182	0/009	−0/655	−0/397	−0/310
(A3, A5)	−0/579	0/146	−0/579	−0/484	−0/044	0/647
Alternative 4	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**
(A4, A1)	0/647	1/017	1/034	1/152	1/466	0/965
(A4, A2)	0/279	1/801	1/905	2/483	1/551	0/879
(A4, A3)	−0/047	0/819	0/991	1/152	1/397	1/310
(A4, A5)	0/259	0/465	−0/088	−0/033	0/853	1/457
Alternative 5	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**
(A5, A1)	0/888	1/053	1/621	1/191	1/113	0/008
(A5, A2)	0/379	1/836	2/492	1/966	1/198	−0/078
(A5, A3)	0/005	0/854	1/579	1/484	1/044	0/353
(A5, A4)	0/742	0/536	1/088	1/033	0/147	−0/457

Using Table 13 and Formula (16), the preferred level of A_Q over A_R in each criterion is calculated. Table 14 presents the values of the preference degrees.

Table 14. $PD_j(A_Q, A_R)$ for different alternatives.

Alternative 1	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**
(A1, A2)	0/218	1/000	1/000	1/000	0/585	0/414
(A1, A3)	0/000	0/302	0/458	0/793	0/431	0/845
(A1, A4)	0/354	0/000	0/000	0/814	0/000	0/035
(A1, A5)	0/112	0/000	0/000	0/000	0/000	0/992
Alternative 2	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**
(A2, A1)	0/782	0/000	0/000	0/000	0/415	0/586
(A2, A3)	0/169	0/000	0/000	0/018	0/346	0/931
(A2, A4)	0/721	0/000	0/000	0/600	0/000	0/121
(A2, A5)	0/621	0/000	0/000	0/000	0/000	1/000
Alternative 3	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**
(A3, A1)	0/543	0/699	0/543	0/207	0/570	0/155
(A3, A2)	1/000	1/000	1/000	0/983	0/655	0/069
(A3, A4)	0/009	0/182	0/009	0/734	0/000	0/000
(A3, A5)	0/000	0/146	0/000	0/000	0/000	0/647
Alternative 4	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**
(A4, A1)	0/647	1/000	1/000	0/186	1/000	0/965
(A4, A2)	0/279	1/000	1/000	0/400	1/000	0/879
(A4, A3)	0/000	0/819	0/991	0/186	1/000	1/000
(A4, A5)	0/259	0/465	0/000	0/000	0/853	1/000
Alternative 5	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**
(A5, A1)	0/888	1/000	1/000	1/000	1/000	0/008
(A5, A2)	0/379	1/000	1/000	1/000	1/000	0/000
(A5, A3)	0/005	0/854	1/000	1/000	1/000	0/353
(A5, A4)	0/742	0/536	1/000	1/000	0/147	0/000

After calculating the preference degrees for all alternatives, the relative preference of A_Q over A_R is calculated using the Formula (17) for each pair of alternatives. The relative preference values for each choice are provided in Table 15.

Table 15. The relative preference values for different alternatives.

Alternative 1	$\pi(A_Q,A_R)$
(A1, A2)	0/635
(A1, A3)	0/471
(A1, A4)	0/153
(A1, A5)	0/241

Table 15. *Cont.*

Alternative 2	$\pi(A_Q, A_R)$
(A2, A1)	0/365
(A2, A3)	0/316
(A2, A4)	0/219
(A2, A5)	0/337
Alternative 3	$\pi(A_Q, A_R)$
(A3, A1)	0/445
(A3, A2)	0/716
(A3, A4)	0/094
(A3, A5)	0/159
Alternative 4	$\pi(A_Q, A_R)$
(A4, A1)	0/847
(A4, A2)	0/781
(A4, A3)	0/716
(A4, A5)	0/504
Alternative 5	$\pi(A_Q, A_R)$
(A5, A1)	0/759
(A5, A2)	0/663
(A5, A3)	0/658
(A5, A4)	0/496

Using the relative preference values for calculating the net flow $\widetilde{\varnothing}(A_i)$ using Formula (18), the calculated values for net flow $\widetilde{\varnothing}(A_i)$ for all alternatives have been exhibited in Table 16.

Table 16. The net flow $\widetilde{\varnothing}(A_i)$ for all alternatives.

	$\tilde{\varnothing}^{+}(A_Q)$	$\tilde{\varnothing}^{-}(A_R)$	$\tilde{\varnothing}(A_Q)$
A1	0/375	0/604	−0/229
A2	0/309	0/699	−0/390
A3	0/353	0/540	−0/187
A4	0/712	0/241	0/471
A5	0/644	0/310	0/334
Ranking	A4 > A5 > A3 > A1 > A2		

In the last step, the net values $\widetilde{\varnothing}(A_i)$ are arranged in descending order. The final ranking of the five companies has been presented in Table 16. The higher the net flow value, the more priority the related company will have.

6. Sensitivity Analysis of Results

Investigating the effects of modifying the model parameters of the criteria is a vital phase of any multi-criteria procedure. Therefore, this section is developed to present a detailed and comprehensive sensitivity analysis by defining different scenarios. In order to achieve this objective, the significant factor of one criterion is raised by 50% in each system. In the identical case, the value factors of the remaining criteria are lowered by 50 percent in each of them. As a result, the ranking of the alternatives changes during six strategies in Grey-FUCOM and Grey-PROMATHEE II methods, as presented in Figure 2.

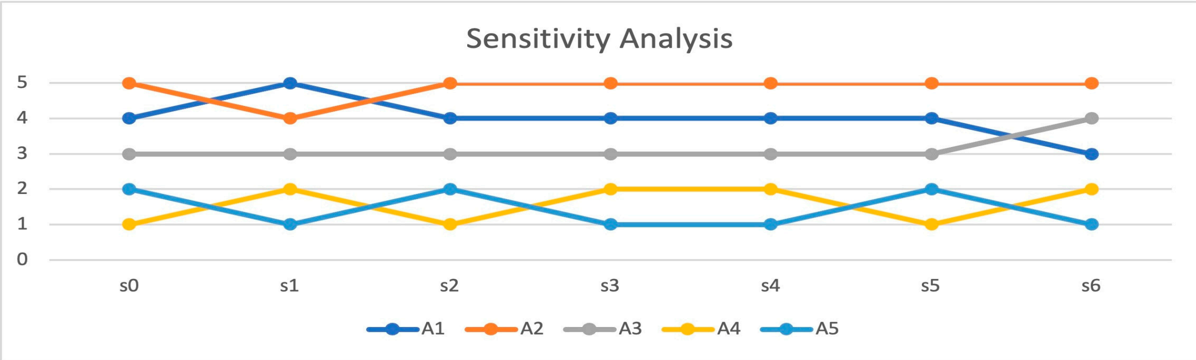

Figure 2. Changes in the final ranking of alternatives during the sensitivity analysis.

Moreover, Spearman's coefficient of correlation was determined to check the stability of the proposed model concerning the changes in the weight coefficient of the criteria. The estimates of Spearman's correlation coefficient were determined by contrasting the starting order of the Grey-FUCOM and Grey-PROMATHEE II (Table 16) with the levels attained by the various situations (Figure 2) as follows:

$$\rho = 1 - \frac{6\sum d_i^2}{n(n^2-1)} \tag{19}$$

where d_i shows the difference in the paired ranks for each alternative regarding the initial ranking, and n presents the number of cases. According to the expression Findings (19) in Figure 3, there is a substantial correlation between rankings since, in each case, the correlation coefficient value is more than 0.8. Additionally, the average correlation coefficient across all instances is 0.9, demonstrating a strong association. By evaluating all correlation analysis estimates as considerably higher than 0.80, it is possible to determine the presence of a strong relation (similarity of orders) and that the recommended sequence is reliable and correct.

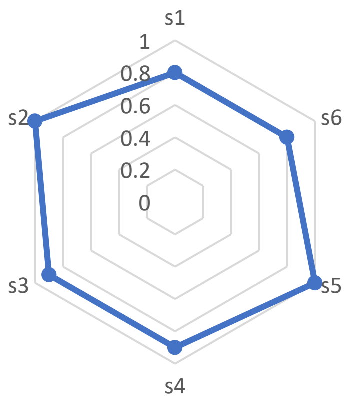

Figure 3. Coefficient values.

7. Conclusions

Summary findings: This research investigates the evaluation of the wheat and barley seed production company by using a new and effective hybrid model. This model is based on grey numbers to cover the vagueness and uncertainties of the expert's judgments. Moreover, the FOCUM was used to determine the weight coefficients of the criteria, which needs only $(n-1)$ comparison by decision makers concerning other procedures such as

AHP and BWM. Similarly, the Grey-PROMATHEE II was used to have a complete and precise ranking for alternatives. This way, the A4 ranks highly among the other companies, and A2 is the last. The results from this method showed sustainable and reliable ranking behavior regarding changing the criteria's weight coefficients.

Implications significance: Improving the processes to assess the wheat and barley seed suppliers results in having a healthier society in the long term. Hence, considering the advantages above and the significance of the seeds' supplier evaluation, the hybrid model presented in this paper can be very efficient in evaluating one of the significant parts of the food supply chain in the initial steps. The proposed methodology for assessing social sustainability in supplier selection has implications for sustainable supply chain management. It addresses the need for more attention to social sustainability in the agricultural sector of emerging economy nations, offering valuable insights for supplier evaluation. Identifying significant criteria and effective suppliers for ecological sustainability contributes to a healthier society and enhances the early stages of the supply chain.

Limitations future research: This research has several limitations. First, its generalizability may be limited to the agricultural industry in emerging economy nations and may not apply to other sectors or territories. Second, excluding a multi-stakeholder viewpoint in the examination process reduces the comprehensiveness and precision of the assessment. Future research for developing the study could be conducted in different directions, such as investigating the green parameters for evaluating the seed companies or sustainable models. Other multi-criteria decision-making strategies might address this model by determining the gaps among outcomes and enhancing supplier evaluation.

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